LANDSAT INVESTIGATION OF WATER QUALITY IN LAKE OKEECHOBEE

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BIOGRAPHICAL SKETCHES

Janette C. Gervin received a BA in physics with general honors from Bucknell University (1969) and an MS in physics from the University of Florida (1971). Her thesis investigated the correlation between solar activity and the decametric emission of Jupiter. After a year of graduate study in planetary physics at UCLA, Ms. Gervin joined the Earth Resources Branch of NASA's Kennedy Space Center in 1973. She has participated in a variety of remote sensing studies in the fields of hydrology, marine resources, X-ray enhancement, laser applications, and crime detection. Ms. Gervin is a member of Phi Beta Kappa, Sigma Xi, and ASP.

Michael L. Marshall is a research biologist for the South Florida Water Management District. He holds a BS (1969) and an MS (1971) in zoology from Western Illinois University, where he was elected to two honorary science fraternities, Beta Beta Beta and Sigma Zeta. He is presently affiliated with the American Society of Limnology and Oceanography, the American Fisheries Society, the Fisheries Research Board of Canada, and the Florida Academy of Science. For the last five years he has been involved in the first large scale limnological study of Lake Okeechobee. His primary areas of interest are phytoplankton, primary productivity, and water quality. More recently he has initiated the first efforts at monitoring the biological and chemical elements of the lake by remote sensing.

ABSTRACT

Multiple regression techniques and LANDSAT radiance values were used to investigate the distribution of turbidity and chlorophyll $\bar{a}$ in Lake Okeechobee on four dates.

For a period of over one year, the South Florida Water Management District sampled the water of Lake Okeechobee for chlorophyll $\bar{a}$ and turbidity at times of LANDSAT overpass.

Using an overlay map of the sampling stations, LANDSAT radiance values were measured from computer compatible tapes using a GE Image 100 and averaged over an 8.9 hectare (22-acre) area at each station. These radiance values in four bands were used to form a number of mathematical functions (powers, logarithms, exponentials, and ratios), which were then compared with the ground measurements using multiple linear regression techniques.

Best fit equations were selected and used to generate maps of turbidity and chlorophyll $\underline{a}$ distribution in the lake on four dates. These distribution patterns were examined and compared. Possible relationships between water parameters and bottom contours, lake stage, wind stress, and tributary inflows were discussed.

INTRODUCTION

Lake Okeechobee is the major storage basin for surface water in southern Florida, providing water for urban and agricultural uses and supplying the headwaters of the Everglades. Located 100 miles north of the southern tip of the peninsula, it is one of the largest lakes in the United States and one of the few fresh water lakes in the semitropics. Its 1820 km^2 (450,000 acre) surface extends about 55 km (35 miles) north-south and about 49 km (30 miles) east-west. Lake Okeechobee is relatively shallow; its mean depth is usually less than three meters with a maximum depth of less than five meters. The lowest contour of the lake's saucer-shaped basin lies just below mean sea level.

The lake and its tributaries and distributaries have been considerably altered by various attempts at water management in the northern Everglades. All major inflows and outflows of the lake, except Fisheating Creek on the west, have flow control structures associated with them, some of which are capable of pumping water into or out of the lake depending upon flood control and water supply requirements. The lake itself is surrounded by a dike (top at approximately 38 feet MSL), which was designed to prevent storm surges which accompany tropical storms from flooding developed land adjacent to the lake.

A water quality survey of Okeechobee by the U. S. Geological Survey found the lake to be in the early stages of eutrophication in 1940. The South Florida Water Management District (then the Central and Southern Florida Flood Control District), which became responsible for managing the lake in 1949, has recently instituted a number of environmental studies to establish the current condition of the lake and to monitor the nature, extent, and source of possible changes.

Extensive biological and chemical investigations (Davis and Marshall, 1975; Marshall, unpublished) indicate that the lake is turbid (17.8 JTU average) with little light penetration (0.59 m average Secchi depth). This turbidity is thought to originate mainly from the resuspension of bottom muds due to wind stress.

The lake's phytoplankton is dominated by blue-green algae and diatoms. Concentrations of phytoplankton as high as 298, 633 units/ml (23, 454, 677 microns^3/ml by biovolume) are reached in the summer. One of the major goals of the environmental studies is to trace seasonal and areal patterns of phytoplankton populations.

Lake Okeechobee represents a valuable natural resource, both as a fresh water reservoir and a wildlife habitat. The Water Management District needs information on water parameters and lake processes to develop water management plans designed to allocate the available water among potential users while preserving the required water quality and quantity. Turbidity and chlorophyll $\bar{a}$ (a major plant pigment in phytoplankton) are among the best indicators of lake condition and trophic status because they are closely related to light penetration, primary productivity, and nutrients. Lake sampling programs have provided information for water management decisions but, due to the size of the lake, this is a costly and incomplete method.

For these reasons NASA and the Water Management District entered into a joint project to develop a reliable and thorough lake-wide water quality monitoring system based on satellite data. The primary goal was to derive relationships between water quality parameters and LANDSAT radiance, which could be used to generate satellite maps of turbidity and chlorophyll $\bar{a}$ distribution for the entire lake on a given day from a limited number of sampling stations. More basic relationships which could be applied to many dates were also sought. The water parameter maps could be used to study circulation patterns, tributary inflows, and fundamental lake processes affecting water quality. The result would be a better understanding of the lake, more accurate predictions of changes due to natural and manmade conditions, and improved evaluation of available water management alternatives.

This paper describes some preliminary results of the joint study and, in particular, deals with the effort to use LANDSAT radiance values to map the distribution of turbidity and chlorophyll $\bar{a}$ in Lake Okeechobee.

DATA ACQUISITION AND ANALYSIS

The data acquisition and analysis is described in four parts: collection of the surface truth, measurement of LANDSAT radiance, application of multiple linear regression techniques to the data, and generation of turbidity and chlorophyll $\bar{a}$ maps for the lake.

Surface Measurements

Water Management District personnel collected surface measurements of turbidity, chlorophyll $\bar{a}$, carotenoids, and various nutrients at 20 stations on days of LANDSAT overpass. Figure 1 shows the locations of the sampling stations used in this study. Most stations were located by means of navigational markers and natural landmarks. Stations in the more interior portions of the lake were located using course headings, speed, and time relationships.

Two liter surface samples were collected by helicopter generally between 9:00 and 11:00 a.m., near the time of LANDSAT overpass. Samples were stored on ice and returned to the laboratory for analysis.

Samples for pigment analyses were filtered through 0.45 micron (pore size) Whatman glass fiber filters and frozen until analyzed. Filter pads and algae were ground with a Thomas-type tissue grinder (0.13-0.18 mm clearance) and the soluble components were dissolved in 90% acetone. Samples were then generally allowed to extract overnight before spectral analysis on a Coleman 124D Spectrophotometer. Chlorophyll $\bar{a}$ was determined using the trichromatic method (Strickland and Parsons, 1968). The time that elasped from sample collection through filtration was generally less than four hours.

Turbidity was measured with a Hach Laboratory Turbidimeter (Model 1860A).

Wind direction and strength (expressed as the Effective Displacement Index, Ayers et al., 1958) were measured at three stations: Station A, near the city of Okeechobee on the north shore of the lake; Station B, at Port Mayaca on the east shore; and Station C, near Clewiston on the south shore (see Figure 1). Anemometers were located on top of the levee that surrounds the lake. The Effective Displacement Index is a weighted average of wind speed and duration for seven days preceding the sampling date. The wind direction (in degrees with 0° = north) gives the direction from which the prevailing wind was blowing.

LANDSAT Radiance Measurements

Four dates which exhibited significant variation in chlorophyll $\bar{a}$ concentration were selected. Surface water quality measurements and satellite data for these days (October 19, 1974, February 4, 1975, May 5, 1975, and September 8, 1975) are presented in Tables 1 through 4. LANDSAT computer compatible tapes for these dates were displayed on a General Electric Multispectral Image Analyzer, the Image 100, which is located at the Kennedy Space Center. An overlay map of the 20 sampling stations was superimposed on an image of the lake and radiance values were measured in LANDSAT Bands 4 (green), 5 (red), 6 (near infrared), and 7 (middle infrared). These values were averaged over a 20 pixel (8.9 hectare) area at each site so that the effect of errors in locating the ground stations would be minimized.

LANDSAT radiance values were then compared with the surface measurements of turbidity and chlorophyll $\bar{a}$ using multiple linear regression techniques.

Multiple Regression Analysis

In order to investigate some nonlinear relationships between radiance and water parameters, various mathematical functions (powers, logarithms, and exponentials) of the bands were calculated. Ratios of one band to another were also examined since the ratio may compensate for variations due to sun angle (seasons) (Yarger and McCauley, 1975). The logarithm of chlorophyll $\bar{a}$ was also compared to radiance to consider more complex exponential relationships.

Multiple regression techniques were used to calculate the correlation of individual radiance functions with water parameters and to seek an empirical best fit equation capable of predicting these ground measurements. The statistical reliability of these results was indicated by the multiple correlation coefficient and other statistical parameters discussed below.

In order to produce an equation with a manageable number of terms, mathematically similar functions (e.g., negative exponentials) were grouped in the analysis and the least significant contributors to the equations were removed based on their relative t-values. The nature of the data, the intrinsic error due to field and laboratory techniques, and the requirements of potential users were employed to establish suitable criteria for selecting best fit equations. The goals chosen for turbidity and chlorophyll $\bar{a}$ were correlation coefficients of 0.80 and 0.70, respectively. The reliability and accuracy of the best fit equations at these correlation levels were examined using the F-value and the standard error of estimate. The F-value expresses the level of confidence, the probability that a given regression equation is not the result of chance. The standard error of estimate indicates the variation between the measured and the calculated values of the water parameters.

Turbidity and Chlorophyll $\bar{a}$ Maps

Best fit equations were used to generate computer maps of turbidity and chlorophyll $\bar{a}$ distribution for the four dates. Correlation coefficients and simplicity of display determined which equations were selected. The best fit equations, their corresponding multiple correlation coefficients, standard errors of estimate, and levels of confidence are presented in Tables 5 through 7. The maps were smoothed over 36 pixel areas so that they might be more readily used in the study of circulation and distribution patterns. Similar ranges of turbidity and chlorophyll $\bar{a}$ were selected for all maps to facilitate comparison between dates while minimizing the loss of detail.

RESULTS

Maps displaying the distribution of turbidity and chlorophyll $\bar{a}$ are described below. The equations used to generate these maps are presented in Tables 5 through 7. Figures 3 through 6 correspond to the equations in Table 5, Figures 7 through 10 to those in Table 6, and Figures 11 through 14 to those in Table 7. Blank areas within the lake represent shoals, data drops, and clouds. There is a cloud in the west central lake on February 4 and one in the north end on May 5. Clouds are scattered along the northern, eastern, and southern shores on September 8.

Turbidity Maps

On October 19, 1974, the lowest turbidity (0-11 JTU, yellow) occurs in Fisheating Creek and along the western shore of Lake Okeechobee from south of the creek to the Kissimmee River in the northwest (Figure 3). The next higher band of turbidity (12-22 JTU, light green) parallels the shoreline and extends eastward across the rocky reef in the southern section of the lake. The 23-30 JTU (green) turbidity level lies closer to the center of the lake but still follows the shoreline. This level reaches in a northwesterly direction into the north section of the lake and is interrupted in the south by a band of 12-22 JTU (light green) turbidity which lies over the rocky reef. The 31-38 JTU (blue) turbidity level extends slightly toward the north but primarily encompasses the high turbidity area (39-50 JTU, purple) in the east central portion of the lake. Another area of high turbidity occurs at the base of Ritta Island near the south shore. (The bank line in the south central lake is a data drop.)

Turbidity levels for February 4, 1975, were not well defined (Figure 4). The lowest turbidity (0-11 JTU, yellow) borders the northwestern shore of the lake. The 12-22 JTU (light green) level intermixes with the lowest turbidity on its lakeward side, borders the northeastern and southern shores, and extends into the interior of the lake. A triangular projection extends southward over the north central section into the 23-30 JTU (green) pattern that occupies most of the center of the lake. The highest turbidity (31-50 JTU, purple-blue) is concentrated in the west central part of the lake.

On May 5, 1975, the region of the lowest turbidity (0-11 JTU, yellow) lies south of the rocky reef (Figure 5). The next higher level (12-22 JTU, light green) borders this region on the lakeward side and extends northward along the western shore to Fisheating Creek. The region of 12-22 JTU (light green) turbidity which occurs in the north end of the lake probably corresponds to a cloud shadow. A band of 23-30 JTU (green) turbidity stretches from north of the center of the lake, west and southwest, toward the western shore and Fisheating Creek. A zone of 31-38 JTU (blue) is located near the east central shore and a narrow band of the same turbidity borders the low turbidity region in the south. The highest turbidity (39-50 JTU, purple) occupies the remainder of the lake, including streaks in the 23-30 JTU (green) area.

The range of turbidity was lower on September 8, 1975 (Figure 6). As a result, there are only two levels of turbidity shown. The lower level (0-11 JTU, yellow) occupies the south end of the lake and the east and west shorelines, while a zone of higher turbidity (12-22 JTU, light green) extends from east of the north shoal southward to the rocky reef.

While the Band 5 turbidity maps do not represent the same level of confidence or accuracy as the maps that are based on two bands, they are much simpler and less costly to generate. The Band 5 maps for October 19, February 4, and September 8 are a reasonably accurate representation of turbidity conditions in the lake.

For October 19, 1974, and September 8, 1975, the turbidity maps based on Band 5 are almost identical to those generated using the regression equations in Table 5 (Figures 7 and 10).

The Band 5 turbidity map for February 4, 1975, shows much less overlap of the turbidity zones than the Band 6-Band 7 map but the basic pattern is very similar (Figure 8). The lowest turbidity (0-11 JTU, yellow) occurs along the western bank from Fisheating Creek to the north end. The next level (12-22 JTU, light green) extends from south of the rocky reef along the western, northern, and northeastern shores with a triangular projection southward in the north central lake. The higher turbidities occupy the interior of the lake and lie in concentric rings. The highest turbidity (38-50 JTU, purple) occurs in the west central section. The boundary between the 23-30 JTU (green) level and the 31-37 JTU (blue) level coincides with the outer edge of highest turbidity zone in the Band 6-Band 7 map for February 4.

The Band 5 turbidity map for May 5 is similar to the Band 4-Band 5 map but displays less detail and some differences in overall turbidity level (Figure 9). The lowest turbidity still occurs south of the rocky reef and extends north to Fisheating Creek. Turbidity in most of the lake is 31-38 JTU (blue) with a zone of lower turbidity (23-30 JTU, green) on the east central shore and a few streaks of higher turbidity (39-50 JTU, purple) in the central area. The 23-30 JTU (green) turbidity also occurs in the north end of the lake and borders the lower turbidity region in the south end.

The equations on which the Band 5 turbidity maps are based have a similar form on all dates and similar slopes on three dates (Table 6). On May 5 removing three sampling stations near the cloud shadow in the north end of the lake from the regression analysis results in a slope of 12.9 (Figure 9). Only September 8 exhibits a significantly different slope and on that date the satellite scanner gains were set at a much higher level. Thus, the relationship between turbidity and LANDSAT radiance in Band 5 can be extended to other dates with some confidence.

Chlorophyll a Maps

The October 19, 1974, chlorophyll $\bar{a}$ map has concentric rings of different concentrations (Figure 11). The lowest chlorophyll $\bar{a}$ level (0-10 mg/m^3, yellow) forms a band in the central portion of the lake, parallel to the northeastern and western shorelines, and separates an inner zone of 21-30 mg/m^3 (blue-green) from an outer region of 31-40 mg/m^3 (violet). This outer region of 31-40 mg/m^3 (violet) extends across the rocky reef. A zone of 0-10 mg/m^3 (yellow) chlorophyll $\bar{a}$ separates the 31-40 mg/m^3 (violet) zone from a patch of 21-30 mg/m^3 (blue-green) which encircles Ritta Island near the south shore. The area with 11-20 mg/m^3 (light green) chlorophyll $\bar{a}$ concentration forms a ring in the east central portion of the lake, within the 21-30 mg/m^3 (blue-green) zone; lines the north shore; and parallels much of the western shore. The highest chlorophyll $\bar{a}$ concentration (41-60 mg/m^3, purple) occurs at the mouth of Fisheating Creek and along the western shore to the north and south.

On February 4, 1975, few areas of the lake have the lowest chlorophyll $\bar{a}$ concentration (0-10 mg/m^3, yellow) (Figure 12). Most of the north and south portions of the lake have 11-20 mg/m^3 (light green) of chlorophyll $\bar{a}$. A triangular region of 11-20 mg/m^3 (light green) chlorophyll $\bar{a}$ reaches southward into the 21-25 mg/m^3 (green) zone which encircles the central portion of the lake. The chlorophyll $\bar{a}$ in the west central portion of the lake is 26-30 mg/m^3 (blue). The highest chlorophyll $\bar{a}$ concentration (31-40 mg/m^3, violet) appears on the western shore from Fisheating Creek to the Kissimmee River.

On May 5, 1975, the lowest chlorophyll $\bar{a}$ level (0-10 mg/m^3, yellow) extends from Fisheating Creek south and east across the rocky reef and northeast along the western shore (Figure 13). Few areas in the lake have 11-20 mg/m^3 (light green) chlorophyll $\bar{a}$ concentration. A band of 21-30 mg/m^3 (blue-green) chlorophyll $\bar{a}$ in the north central part of the lake borders a region of 0-10 mg/m^3 (yellow) chlorophyll $\bar{a}$ to the west, while patches of the 21-30 mg/m^3 (blue-green) concentration appear on the northwestern shore and in the south central portion of the lake. The north, east, and south regions of the lake have primarily 31-40 mg/m^3 (violet) of chlorophyll $\bar{a}$ with zones of higher concentration (41-60 mg/m^3, purple) adjacent to the east shore and forming a small pocket in the southeast corner of the lake.

On September 8, 1975, the lowest level of chlorophyll $\bar{a}$ (0-10 mg/m^3, yellow) occupies the southern, western, and northeastern shores of the lake (Figure 14). Zones of 11-20 mg/m^3 (light green) chlorophyll $\bar{a}$ border the southwestern section and appear in patches in other parts of the lake. There are very few areas with chlorophyll $\bar{a}$ in the 21-30 mg/m^3 (blue-green) range. A large region of 31-40 mg/m^3 (violet) chlorophyll $\bar{a}$ extends from near the mouth of the Kissimmee River southward to the rocky reef. It is flanked on the east and west by two large zones of 41-60 mg/m^3 (purple) chlorophyll $\bar{a}$.

DISCUSSION

Individual correlation coefficients for turbidity, chlorophyll $\bar{a}$, carotenoids, and various nutrients as a function of LANDSAT radiance values for the four dates were presented in Gervin and Marshall (1976). The results of these analyses and their relationship to past hydrological research were discussed in detail.

The current paper focuses on the application of these remote sensing techniques in investigating the distribution of selected water quality parameters in the lake. A knowledge of the factors which influence turbidity and chlorophyll $\bar{a}$ distribution is particularly important for water management planning.

Turbidity patterns in the lake appear to be influenced by the bottom contours (Figure 2). Higher turbidity levels tend to occur in the deeper portions of the lake, while shallow areas are generally less turbid.

Lake Okeechobee is subject to fluctuations of up to four feet in lake stage due to seasonal rains, which can modify the effect of the bottom contours. At the lowest lake stage (11.90 feet MSL on May 5), the rocky reef interferes with circulation between the southern portion and the rest of the lake and apparently prevents more turbid water, which is characteristic of the central lake, from reaching the south end (Figure 5). At intermediate lake stages (14.17 feet MSL on February 4 and 13.27 feet MSL on September 8), the maps still show some isolation of the south end (Figures 4 and 6).

Although a zone of lower turbidity appears over the rocky reef at the highest lake stage (15.50 feet MSL on October 19), turbidity in the south end is relatively high (Figure 3). The higher turbidity in this area is probably not due to improved circulation with the central lake, however. During the month prior to this date, a pumping station had been discharging agricultural runoff into a canal which enters the lake near the base of Ritta Island. Although no water samples were collected at this location, the low levels of turbidity observed on other dates, when the pumping station was not operating, indicate that this turbidity may be due to backpumping.

Turbidity patterns do not appear to be influenced by the location of bottom muds, which are concentrated northeast of the center of the lake. Prevailing winds, coupled with lake stage, may be more significant factors in determining both turbidity and chlorophyll $\bar{a}$ distribution in the lake. Although this relationship is still being examined, a few preliminary observations might be made.

The strong northeast winds on October 19 appear to produce an orderly turbidity distribution (Figure 3). On May 5 the wind direction at Stations A and B varied by almost 180^{o} and the wind stress and turbidity pattern are characterized by a diagonal shear (Figure 5). The southeast winds on February 4 are not as strong and the turbidity is generally disorganized (Figure 4). On September 8 the wind stress is relatively weak and the large inflows from the Kissimmee River and Fisheating Creek appear to determine the turbidity distribution (Figure 6).

At higher lake stages the maximum concentrations of chlorophyll ā occurred on the downwind side of the lake. Thus, on October 19 the highest chlorophyll ā was found along the western shore while on February 4 the greatest concentration bordered the northwestern shore (Figures 11 and 12).

The chlorophyll ā pattern for May 5 (the lowest lake stage) was unique among the four dates (Figure 13). On that day, the wind stress was from the south~~east~~west on the northern shore of the lake and northeast on the eastern shore. Although the chlorophyll ā distribution reflects this diagonal shear, some of the highest chlorophyll ā concentrations are found on the upwind side of the lake. At this low lake stage, with the distance from the top of the levee (at 38 feet MSL) to the lake surface at a maximum, there may have been a shadowing effect which prevented wind-generated waves from redistributing the chlorophyll ā in the lee of the levee.

The chlorophyll ā pattern on September 8 may be due to tributary inflows rather than the relatively weak wind stress (Figure 14). The long central plume of 31-40 mg/m^3 (violet) appears to be related to the Kissimmee River while the 41-60 mg/m^3 (purple) plumes flanking it on the east and west might be the result of discharges from Nubbin Slough and Indian Prairie Canal, respectively.

Comparison between wind stress and water quality parameters indicate that the Effective Displacement Index may need to be redefined for this study. The Index was developed for relatively small lakes and may require averaging over a longer time period for large lakes such as Okeechobee.

Although turbidity may influence chlorophyll ā, the relationship is probably complex. The correlation coefficients between chlorophyll ā and turbidity are −0.56 for October 19, 0.17 for February 4, 0.66 for May 5, and 0.55 for September 8. On October 19 zones of low turbidity tend to have high chlorophyll ā while areas of low chlorophyll ā seem to correspond to intermediate turbidity (Figures 3 and 11). The correlation coefficient for February 4 was not considered significant. On May 5 the higher chlorophyll ā concentrations generally coincided with higher turbidities (Figures 5 and 13). The 41-60 mg/m^3 (purple) chlorophyll ā occurs in an area of 31-38 JTU (blue) turbidity, but the 31-40 mg/m^3 (violet) zone corresponds to both 39-50 JTU (purple) and 0-11 JTU (yellow). On September 8 the highest chlorophyll ā zones (41-60 mg/m^3, purple) occur on the edges of the turbidity plume while the center of this plume is occupied by the second highest chlorophyll ā level (31-40 mg/m^3, violet) (Figures 6 and 14).

It is possible that the relationship between turbidity and chlorophyll ā may vary within the lake on each date, as well as between dates, or that certain favorable or unfavorable combinations of the parameters may exist. These possibilities are presently under investigation.

SUMMARY

Computer maps of turbidity and chlorophyll ā distribution in Lake Okeechobee on four dates were generated from LANDSAT radiance values and a limited number of water quality measurements using multiple linear regression techniques. These maps were described and processes influencing these distributions were discussed.

Turbidity patterns are affected by bottom contours and lake stage, rather than the location of bottom muds. Significant wind stress, tributary inflows, and backpumping may also influence turbidity distribution.

Chlorophyll ā concentration appears to be affected most by wind stress and tributary inflows. Chlorophyll ā may also correlate with turbidity but the relationship is complex and will require further study.

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TABLE 1

OCTOBER 19

SURFACE MEASUREMENTS						LANDSAT RADIANCE			
Station Number	Turbidity	Chlorophyll $\bar{a}$	Station	EDI*	Wind Direction	Band 4	Band 5	Band 6	Band 7
	JTU	mg/m^3							
1	10.0	17.0	A	.2517	75^o	9.00	5.40	3.20	1.05
2	13.0	21.9	B	.0547	103^o	9.50	6.00	3.80	0.85
3	17.0	21.2	C	.3454	71^o	9.25	5.70	3.45	0.75
4	16.0	20.4				9.40	6.15	3.25	1.05
5	21.0	19.2	Average	.2173		9.95	6.45	4.10	0.95
6	21.0	28.9				9.05	5.60	3.50	0.75
7	34.0	23.4				9.90	6.45	3.90	0.85
8	25.0	16.8				10.05	6.40	4.05	0.95
9	5.0	48.3				8.30	4.65	2.70	0.50
10	25.0	24.9				9.10	6.00	3.75	0.85
11	40.0	30.5				10.25	7.10	4.40	1.65
12	35.0	25.6				10.35	6.70	4.50	1.35
13	23.0	28.7				9.45	6.40	3.85	1.20
14	29.0	22.8				10.50	7.25	4.30	1.55
15	45.0	19.5				10.90	7.80	5.00	1.60
16	31.0	20.1				10.20	7.10	4.35	1.85
17	22.0	37.6				9.40	6.45	3.60	0.90
18	22.0	19.2				9.90	6.35	3.80	1.10
19	20.0	30.0				9.50	6.35	3.81	1.00
20	41.0	18.6				10.00	6.85	4.41	1.15
Mean	24.8	24.5				9.70	6.36	3.89	1.10

Lake Stage 15.50 feet MSL

*Effective Displacement Index

TABLE 2

FEBRUARY 4

SURFACE MEASUREMENTS						LANDSAT RADIANCE			
Station Number	Turbidity	Chlorophyll $\bar{a}$	Station	EDI*	Wind Direction	Band 4	Band 5	Band 6	Band 7
	JTU	mg/m^3							
1	6.4	24.8	A	.0999	124°	7.90	4.00	2.05	0.80
2	12.0	20.4	B	.0623	121°	8.05	4.45	2.10	0.55
3	12.0	20.8	C	.1462	64°	8.30	4.90	2.30	0.45
4	16.0	16.6				8.45	4.90	2.45	0.60
5	10.0	9.7	Average	.1028		8.15	4.50	2.45	0.60
6	30.0	28.9				8.35	4.70	2.35	0.35
7	19.0	23.8				8.65	5.55	3.00	0.85
8	17.0	11.5				8.70	5.05	2.55	0.50
9	5.4	29.4				8.00	4.20	2.00	0.45
10	39.0	26.5				8.95	5.80	3.40	0.65
11	33.0	18.9				9.10	6.15	3.85	1.10
12	28.0	22.8				8.75	5.30	3.10	0.80
13	35.0	18.9				9.25	6.25	3.70	1.30
14	37.0	21.5				9.10	6.25	3.70	1.00
15	20.0	15.2				8.75	5.60	3.25	1.10
16	19.0	18.1				8.85	5.45	3.20	0.80
17	24.0	13.8				8.65	5.10	2.50	0.30
18	32.0	18.3				8.95	5.70	3.40	0.95
19	12.0	10.6				8.80	5.35	3.05	1.10
20	22.0	10.5				8.50	5.10	2.90	1.00
Mean	21.4	19.1				8.61	5.22	2.86	0.76

Lake Stage 14.17 feet MSL

*Effective Displacement Index

TABLE 3

MAY 5

SURFACE MEASUREMENTS						LANDSAT RADIANCE			
Station Number	Turbidity	Chlorophyll $\bar{a}$	Station	EDI*	Wind Direction	Band 4	Band 5	Band 6	Band 7
	JTU	mg/m^3							
1	7.0	17.6	A	.3402	253^{o}	15.45	10.00	7.15	3.75
2	22.0	35.9	B	.3502	41^{o}	14.55	9.70	6.15	2.80
3	15.0	28.6	C	----	-	15.60	10.40	6.35	2.70
4	21.0	27.6				15.95	11.20	6.75	2.85
5	42.0	41.5	Average	.3452		15.15	10.85	7.35	3.20
6	37.0	27.4				15.20	9.85	5.90	2.85
7	34.0	30.0				15.80	11.30	7.15	3.30
8	44.0	35.7				15.60	11.30	7.65	3.50
9	10.0	11.9				14.80	9.15	5.90	2.50
10	43.0	27.4				15.40	10.70	6.20	2.90
11	49.0	30.9				15.65	11.20	7.55	3.40
12	38.0	32.6				15.15	10.85	7.10	3.15
13	23.0	12.4				15.40	11.00	6.45	2.50
14	51.0	27.4				15.50	11.35	7.40	2.85
15	44.0	38.9				14.45	10.20	6.90	3.20
16	52.0	33.2				14.75	10.95	7.50	3.70
17	11.0	9.4				13.95	9.10	5.60	2.15
18	31.0	12.6				14.30	9.75	5.60	2.10
19	22.0	15.8				14.00	9.60	5.55	2.15
20	42.0	37.5				13.90	10.20	7.30	3.75
Mean	31.9	26.7				15.03	10.43	6.68	2.96

Lake Stage 11.90 feet MSL

*Effective Displacement Index

TABLE 4

SEPTEMBER 8

SURFACE MEASUREMENTS						LANDSAT RADIANCE			
Station Number	Turbidity	Chlorophyll $\bar{a}$	Station	EDI*	Wind Direction	Band 4	Band 5	Band 6	Band 7
	JTU	mg/m^3							
1	6.9	44.7	A	.1790	111^o	32.1	20.6	3.9	1.6
2	7.2	32.8	B	.0665	104^o	29.3	19.2	3.8	0.9
3	14.0	52.4	C	.1076	109^o	31.9	21.9	4.1	1.2
4	15.0	52.0				32.6	21.6	3.8	1.3
5	8.9	24.4	Average	.1177		31.1	20.9	3.7	0.9
6	17.0	42.5				30.2	20.0	3.7	1.5
7	19.0	51.1				32.3	22.1	4.3	0.7
8	14.0	57.8				31.8	20.7	4.2	1.5
9	3.2	6.8				27.6	17.8	3.7	0.8
10	18.0	45.1				30.4	21.6	4.0	1.2
11	24.0	37.9				32.4	22.9	4.0	1.5
12	9.4	25.2				30.4	20.1	3.5	1.1
13	8.3	5.1				33.4	23.4	3.8	1.4
14	21.0	36.6				32.1	23.0	3.8	1.1
15	12.0	35.6				31.0	20.6	3.8	0.7
16	4.4	12.2				31.1	19.7	3.8	0.9
17	11.0	26.5				30.0	19.6	3.0	0.7
18	19.0	14.6				33.1	23.9	4.0	1.2
19	12.0	17.6				31.3	21.1	3.2	1.2
20	4.0	10.6				31.1	19.8	3.6	1.4
Mean	12.4	31.6				31.3	21.0	3.8	1.1

Lake Stage 13.27 feet MSL

*Effective Displacement Index

EQUATIONS FOR TURBIDITY

OCTOBER 19

Turbidity = 17.8 (B6) - 44.6

Multiple Correlation Coefficient	0.899
Standard Error of Estimate	4.73 JTU

FEBRUARY 4

Turbidity = 22.4 (B6) - 22.3 (B7) - 25.7

Multiple Correlation Coefficient	0.880
Standard Error of Estimate	5.21 JTU

MAY 5

Turbidity = -15.9 (B4) + 22.3 (B5) + 37.7

Multiple Correlation Coefficient	0.787
Standard Error of Estimate	9.43 JTU

SEPTEMBER 8

Turbidity = -2.68 (B4) + 4.81 (B5) - 4.89

Multiple Correlation Coefficient	0.768
Standard Error of Estimate	4.04 JTU

The equations above exceeded the 90% level of confidence.

TABLE 5

EQUATIONS FOR TURBIDITY AS A
FUNCTION OF BAND 5

OCTOBER 19

Turbidity = 12.9 (B5) - 57.1

Multiple Correlation Coefficient	0.865
Standard Error of Estimate	5.42 JTU

FEBRUARY 4

Turbidity = 12.9 (B5) - 46.1

Multiple Correlation Coefficient	0.812
Standard Error of Estimate	6.23 JTU

MAY 5

Turbidity = 12.1 (B5) - 94.8

Multiple Correlation Coefficient	0.618
Standard Error of Estimate	11.66 JTU

SEPTEMBER 8

Turbidity = 2.73 (B5) - 45.0

Multiple Correlation Coefficient	0.706
Standard Error of Estimate	4.34 JTU

The equations above exceed the 75% level of confidence.

TABLE 6

EQUATIONS FOR CHLOROPHYLL A

OCTOBER 19

$$\text{Chlorophyll} = [5.45\times10^{2}]+[(2.93\times10^{5})(e^{-B4})]-[(4.64\times10^{2})(e^{1/B5})]$$

Multiple Correlation Coefficient	0.788
Standard Error of Estimate	5.02 mg/m^3

FEBRUARY 4

$$\text{Chlorophyll} = -[1.76\times10^{3}]-[6.28e^{B7}]+[(6.06\times10^{2})(e^{1/B6})]+[(1.32\times10^{3})(e^{-1/B6})]$$

Multiple Correlation Coefficient	0.701
Standard Error of Estimate	4.64 mg/m^3

MAY 5

$$\text{Chlorophyll} = [7.96\times10^{1}]-[1.03e^{B7}]+[(2.10\times10^{7})(e^{-B4})]-[(6.46\times10^{2})(e^{-B7})]$$

Multiple Correlation Coefficient	0.880
Standard Error of Estimate	5.15 mg/m^3

SEPTEMBER 8

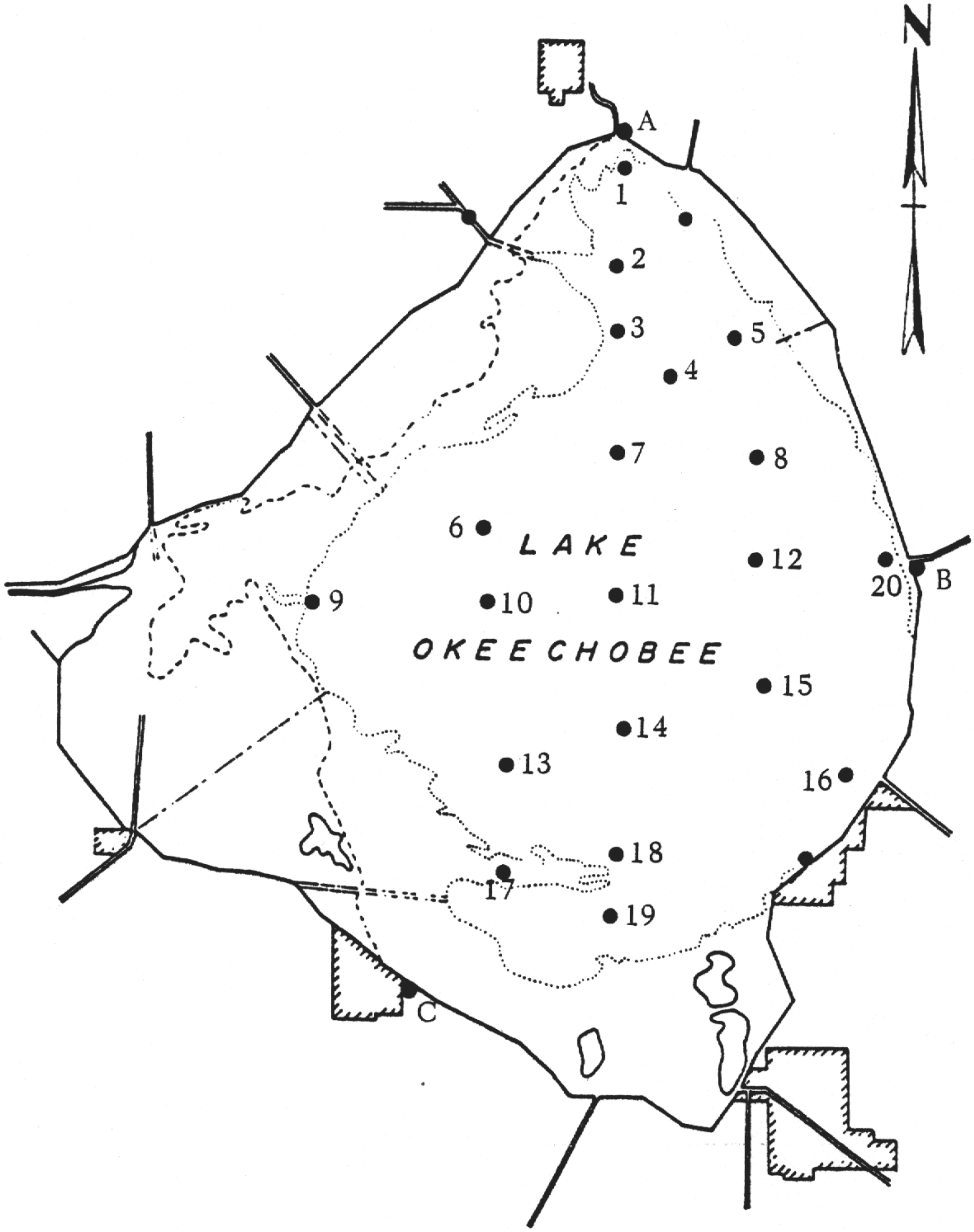
$$\text{Chlorophyll} = [4.24]-[(1.44\times10^{-9})(e^{B5})]+[(7.94\times10^{-1})(e^{B6})]-[(1.70\times10^{9})(e^{-B5})]$$

Multiple Correlation Coefficient	0.803
Standard Error of Estimate	10.75 mg/m^3

The equations above exceeded the 90% level of confidence.

TABLE 7

FIGURE 1



LAKE OKEECHOBEE WATER QUALITY SAMPLING STATIONS

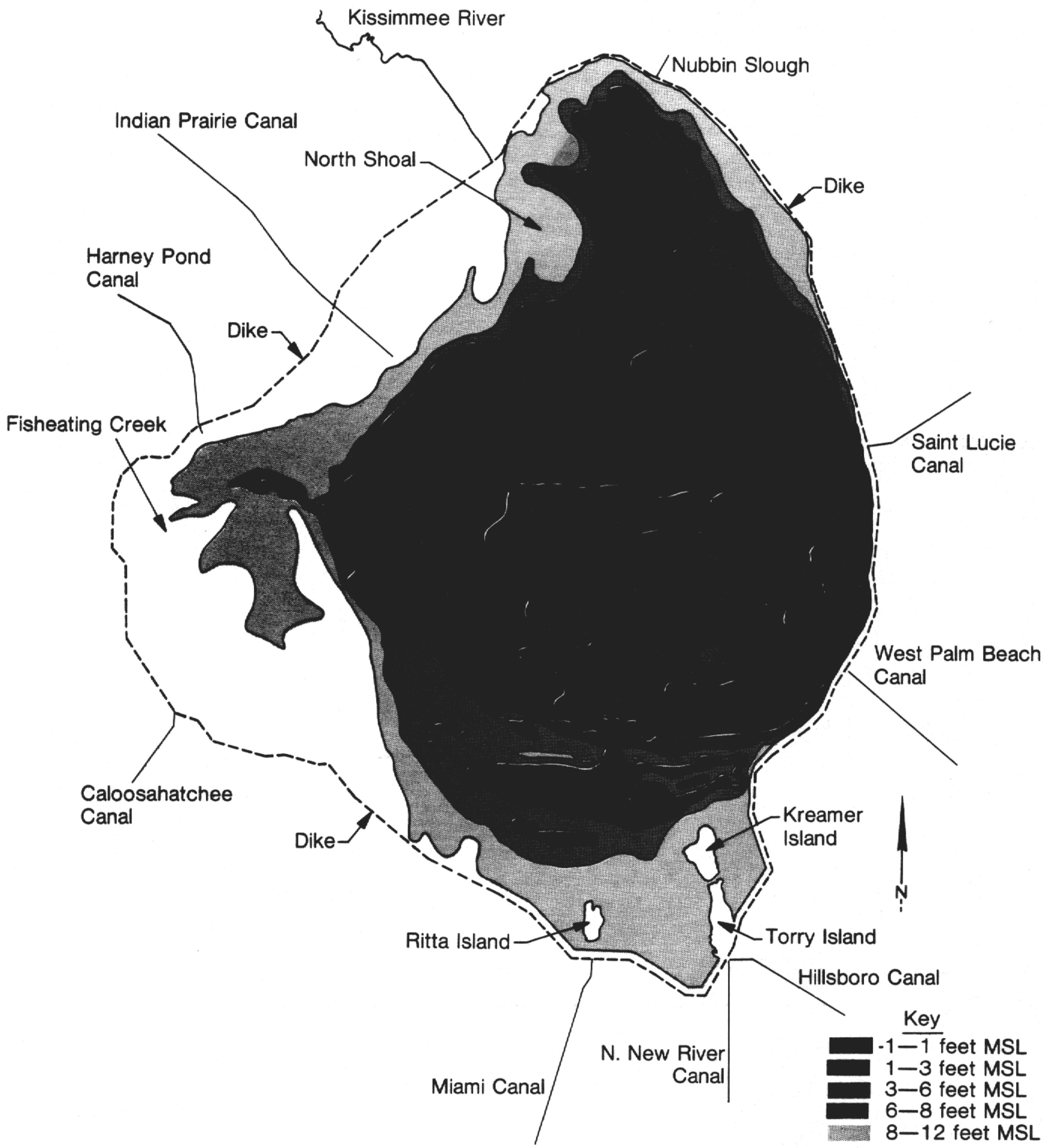


Figure 2. Bottom Contour Map of Lake Okeechobee

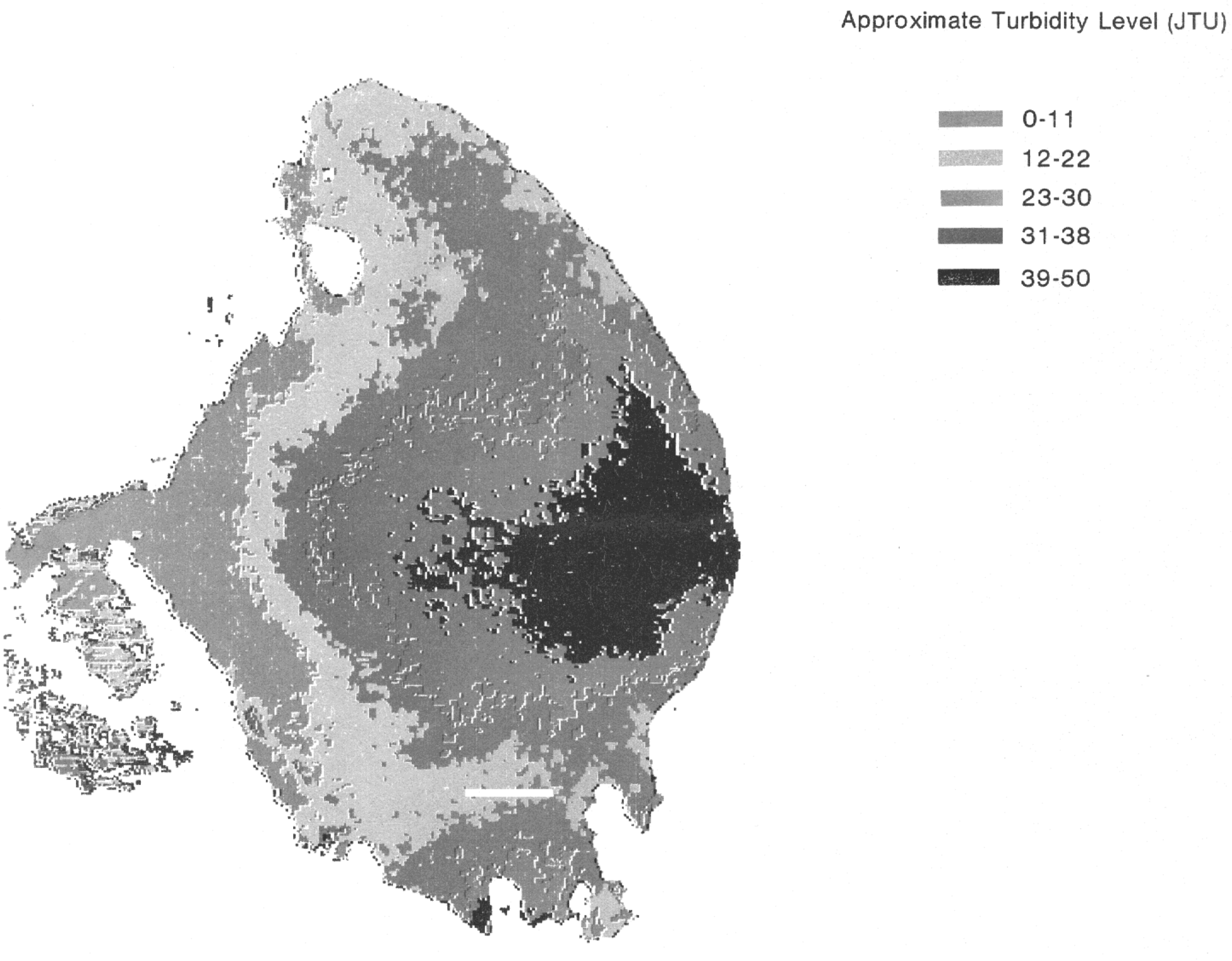


Figure 3. Turbidity distribution in Lake Okeechobee on October 19, 1974, based on LANDSAT radiance in Band 6.

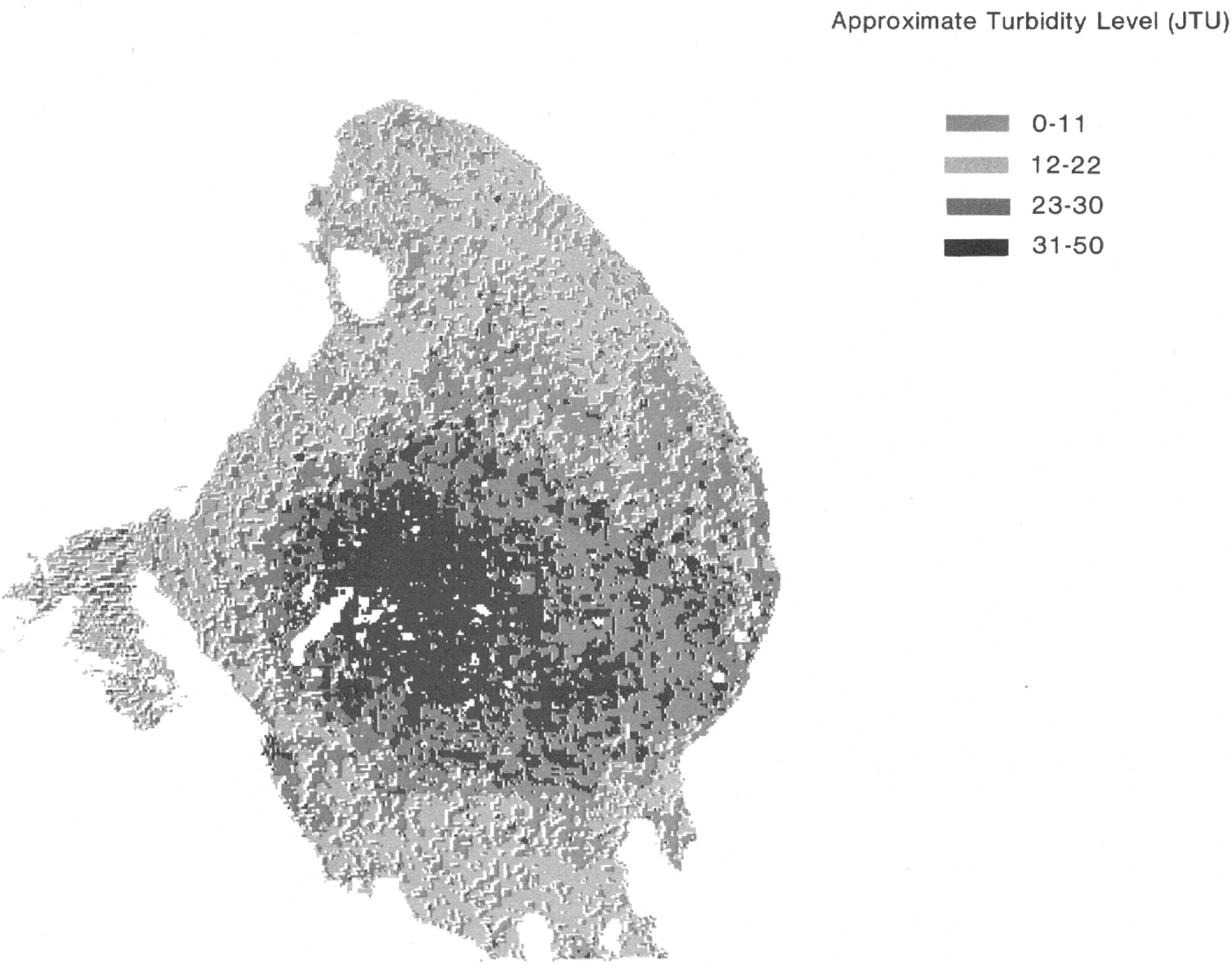


Figure 4. Turbidity distribution in Lake Okeechobee on February 4, 1975, based on LANDSAT radiance in Bands 6 and 7.

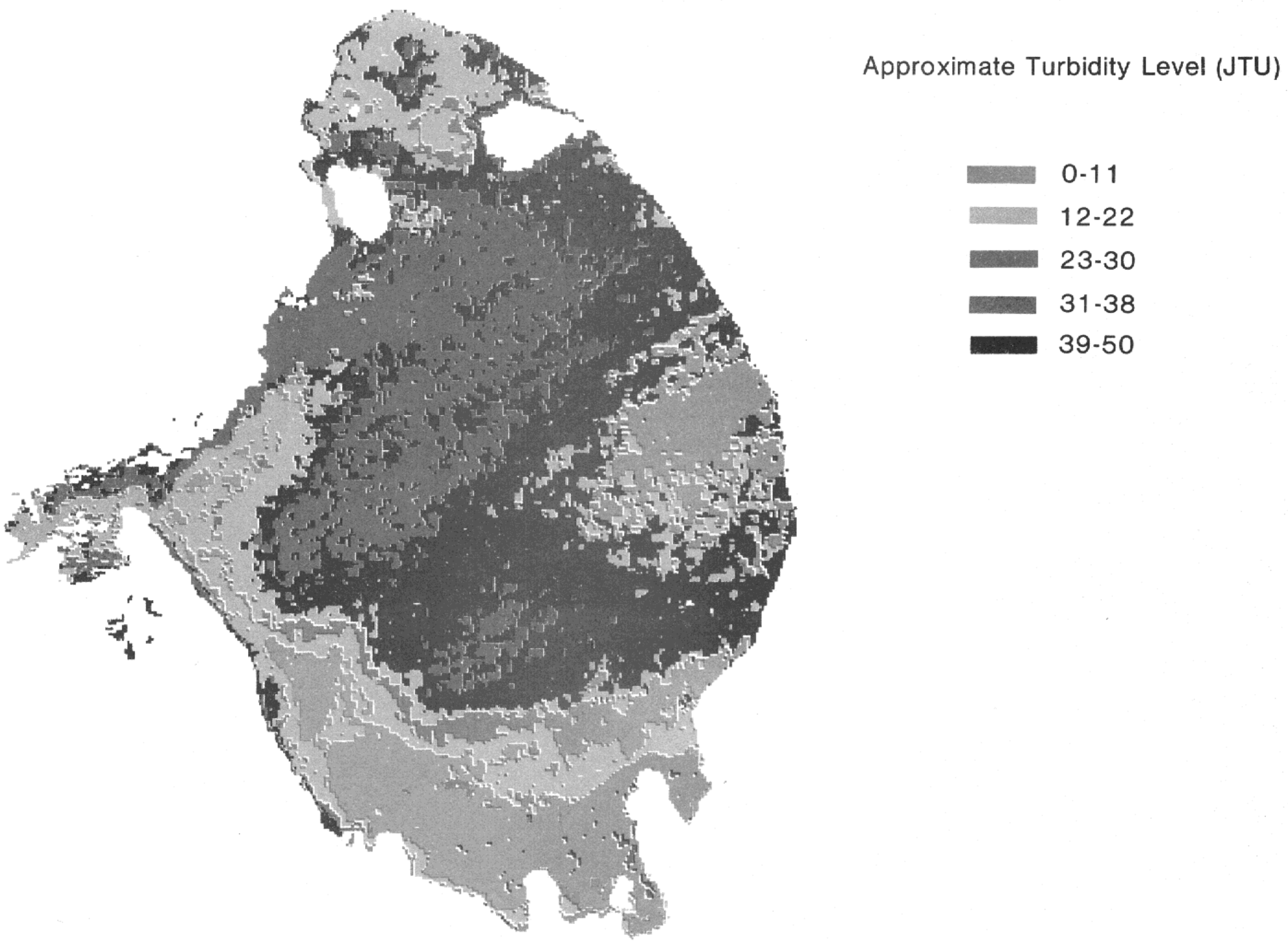


Figure 5. Turbidity distribution in Lake Okeechobee on May 5, 1975, based on LANDSAT radiance in Bands 4 and 5.

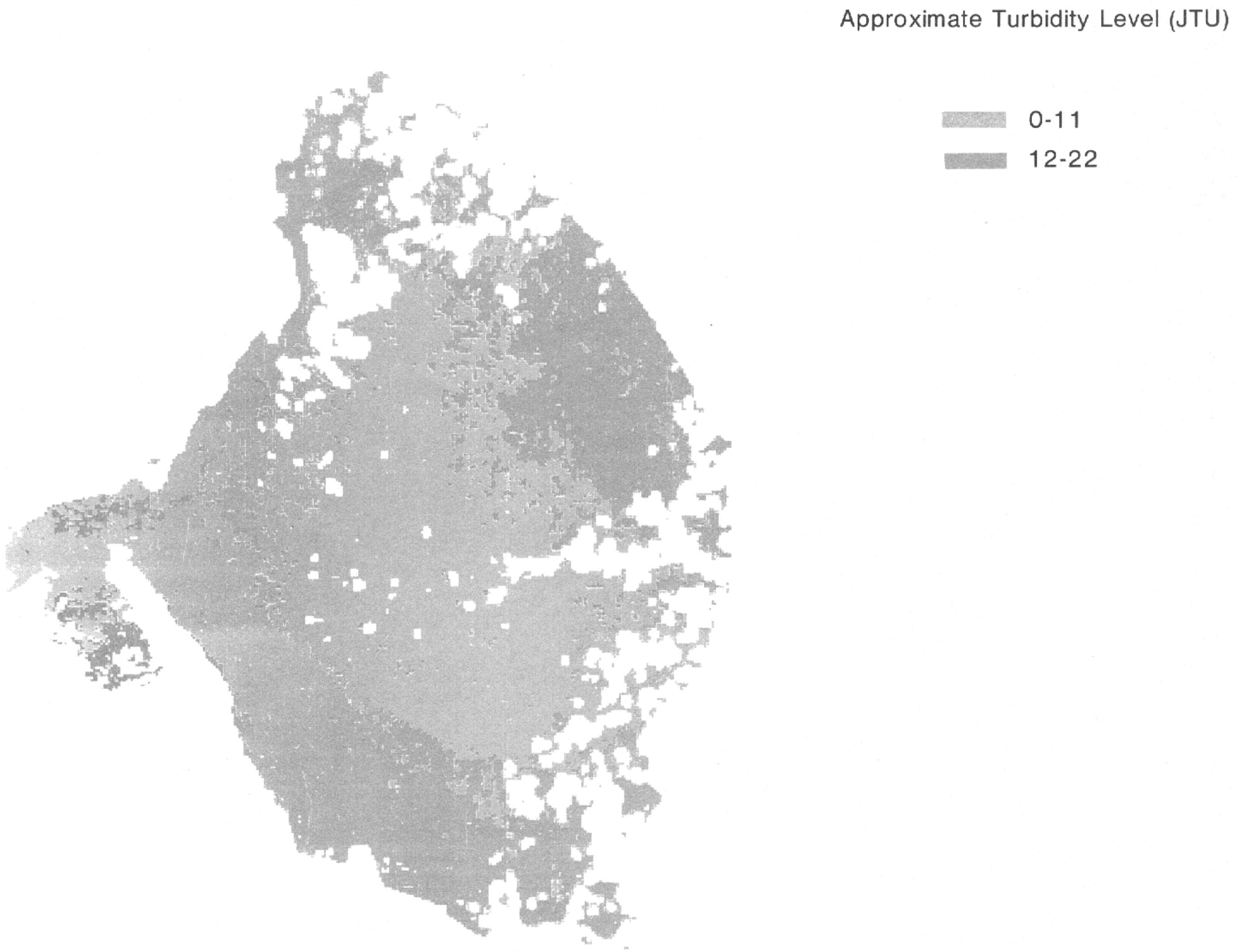


Figure 6. Turbidity distribution in Lake Okeechobee on September 8, 1975, based on LANDSAT radiance in Bands 4 and 5.

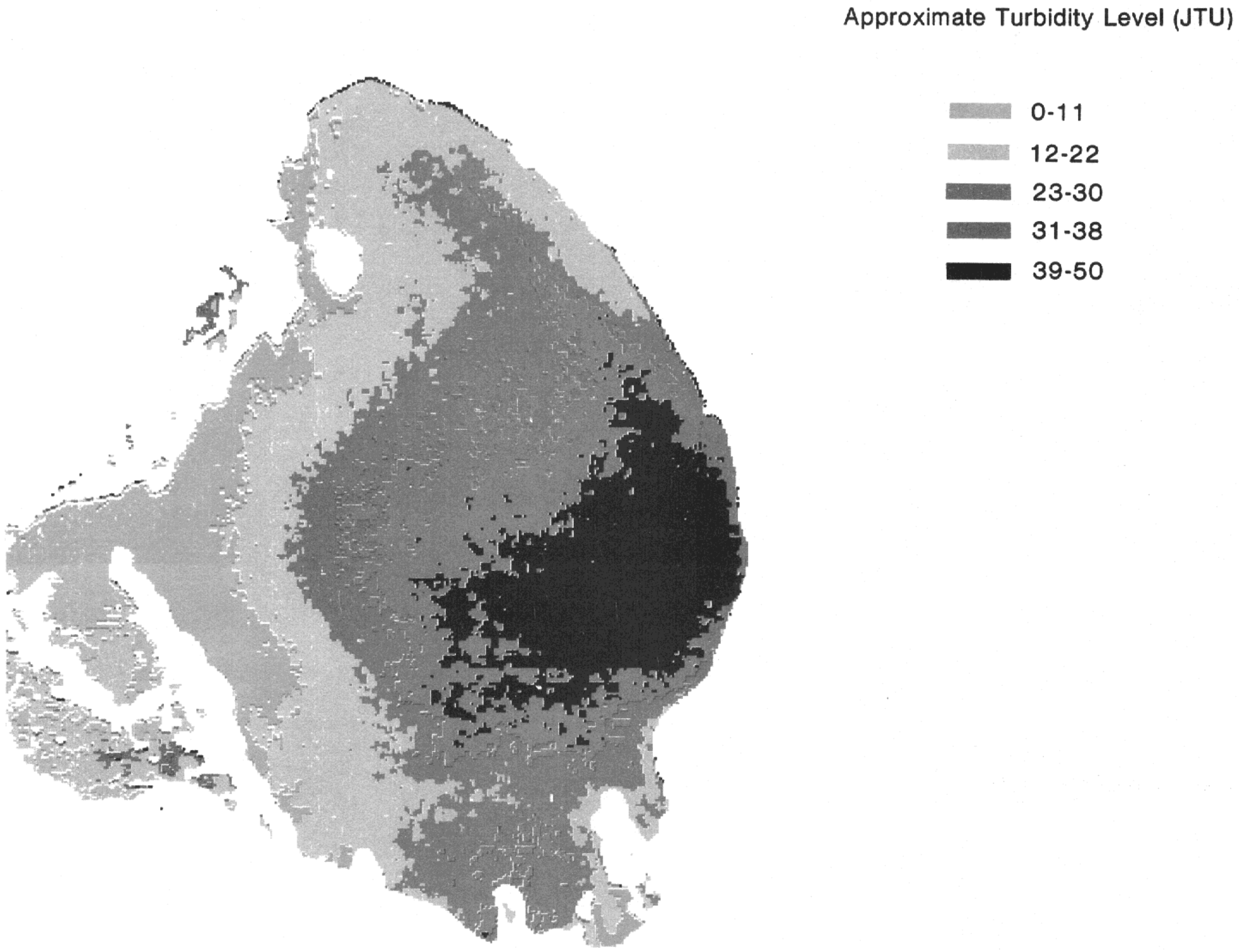


Figure 7. Turbidity distribution in Lake Okeechobee on October 19, 1974, based on LANDSAT radiance in Band 5.

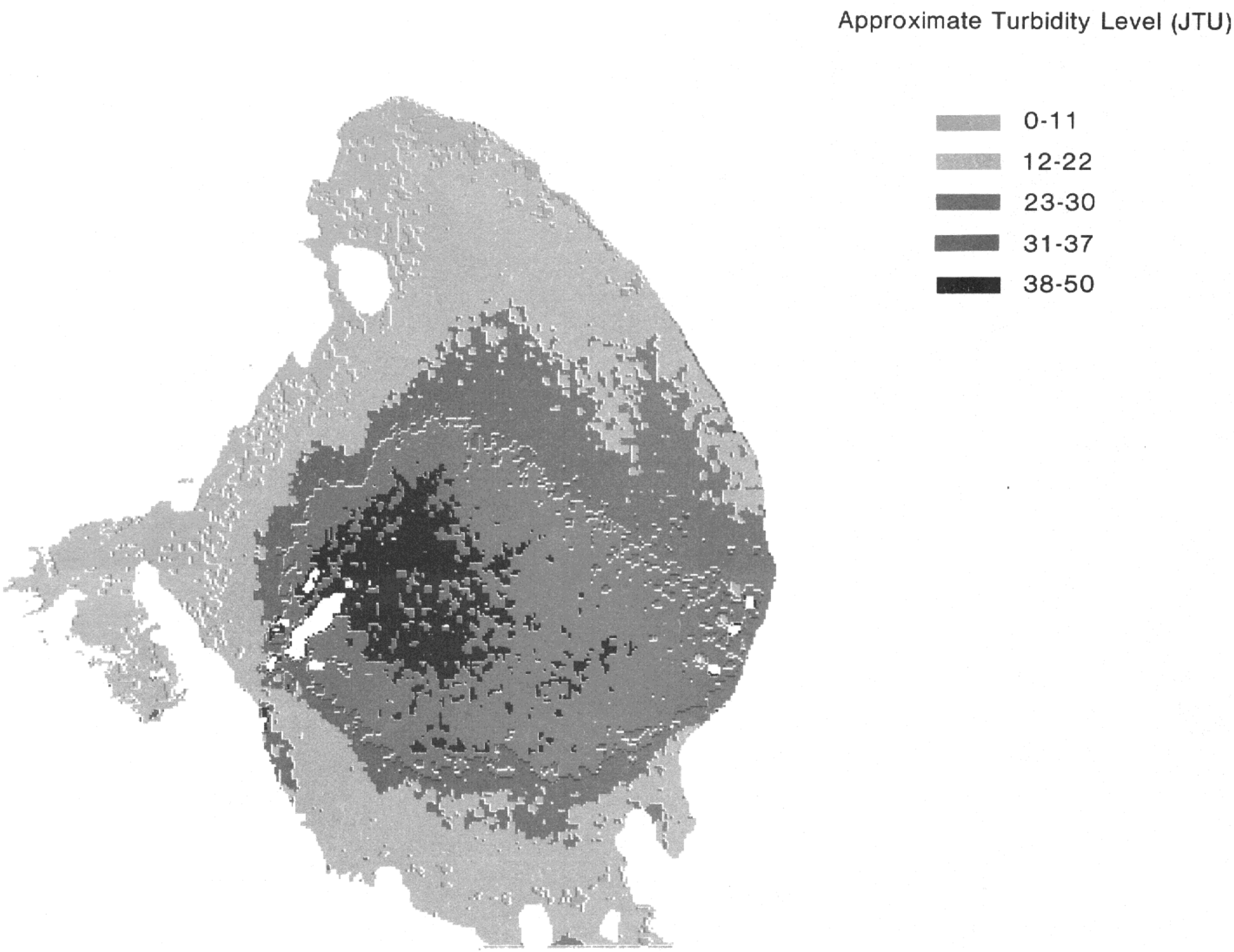


Figure 8. Turbidity distribution in Lake Okeechobee on February 4, 1975, based on LANDSAT radiance in Band 5.

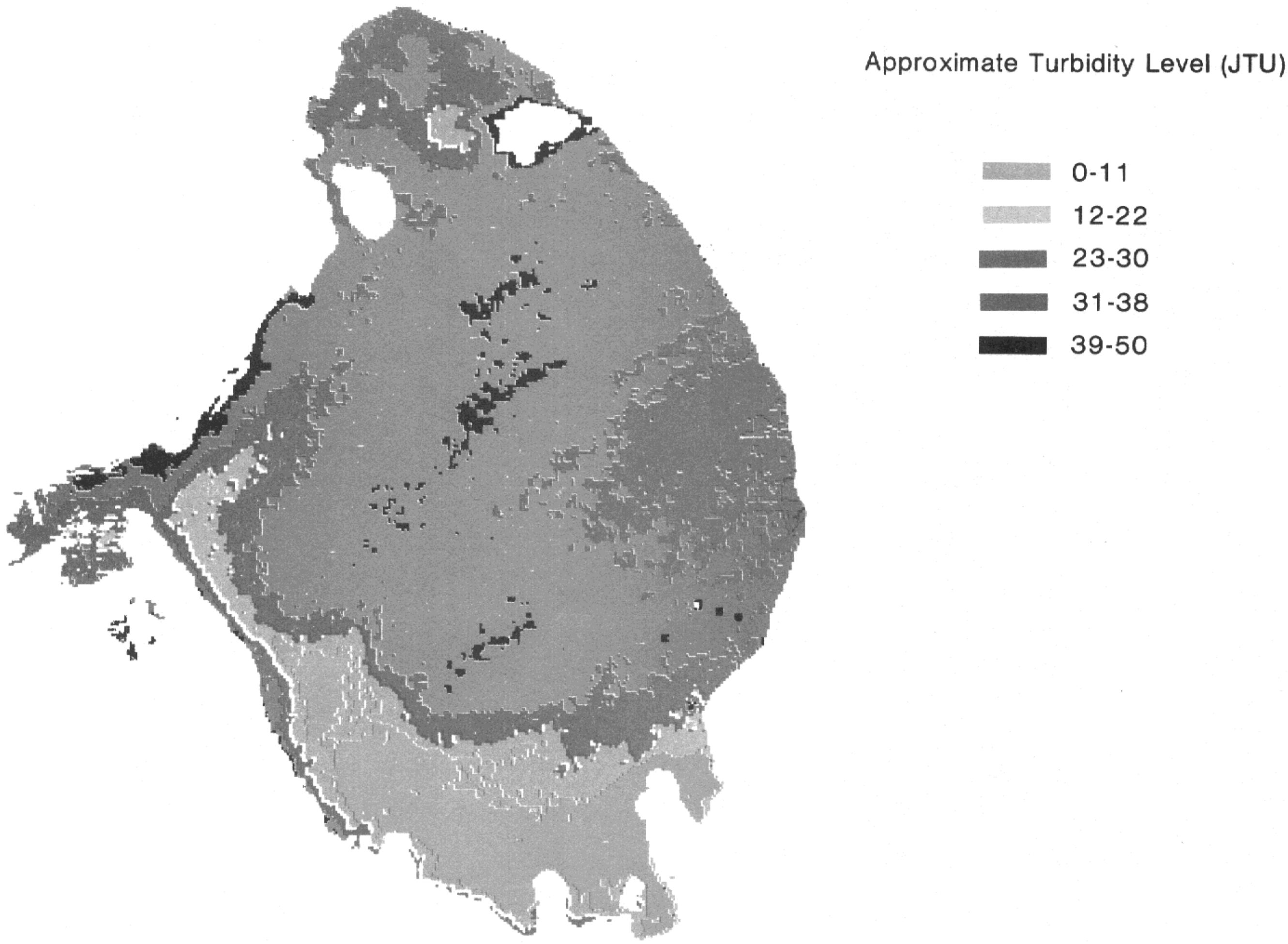


Figure 9. Turbidity distribution in Lake Okeechobee on May 5, 1975, based on LANDSAT radiance in Band 5.

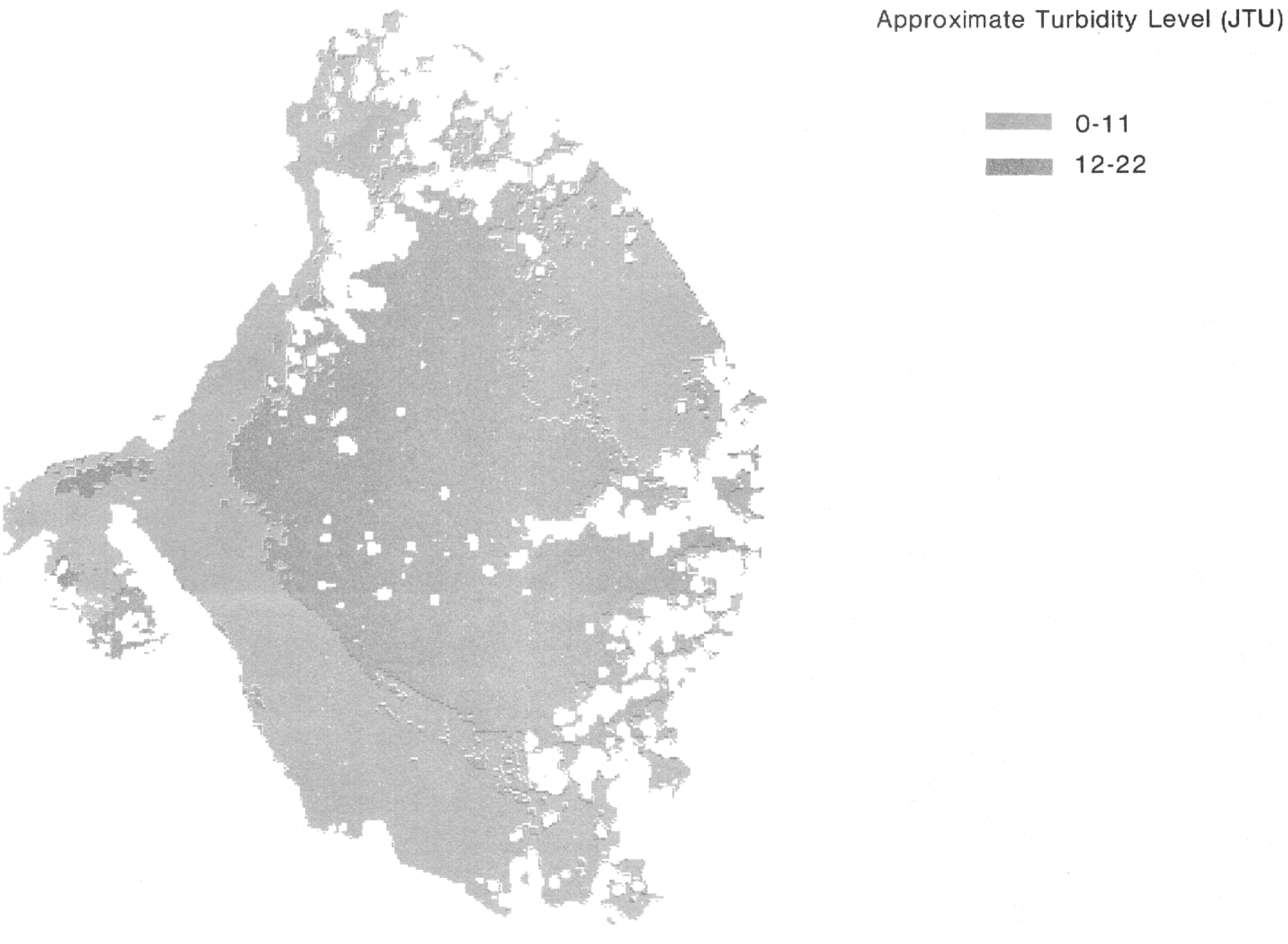


Figure 10. Turbidity distribution in Lake Okeechobee on September 8, 1975, based on LANDSAT radiance in Band 5.

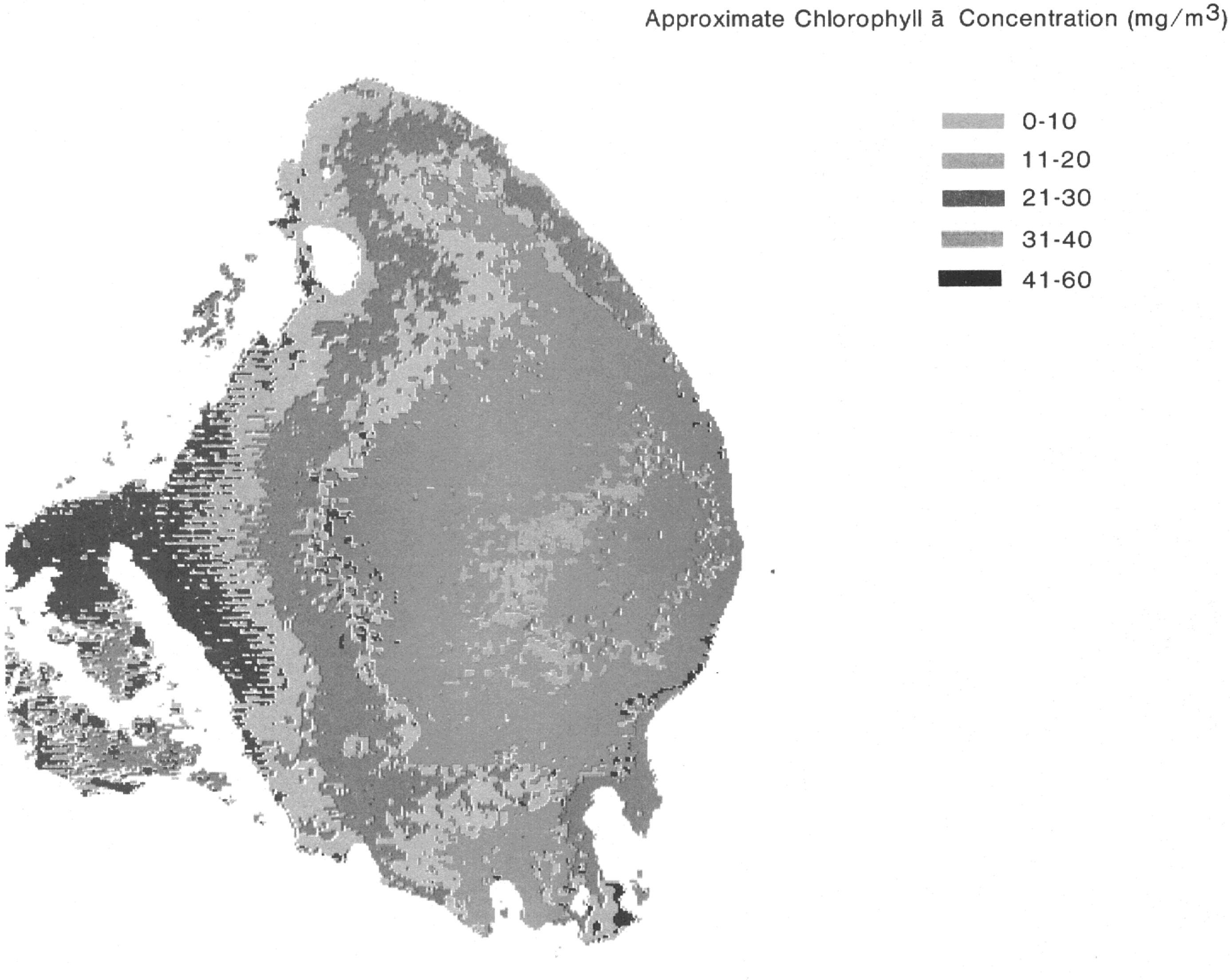


Figure 11. Chlorophyll ā distribution in Lake Okeechobee on October 19, 1974, based on LANDSAT radiance in Bands 4 and 5.

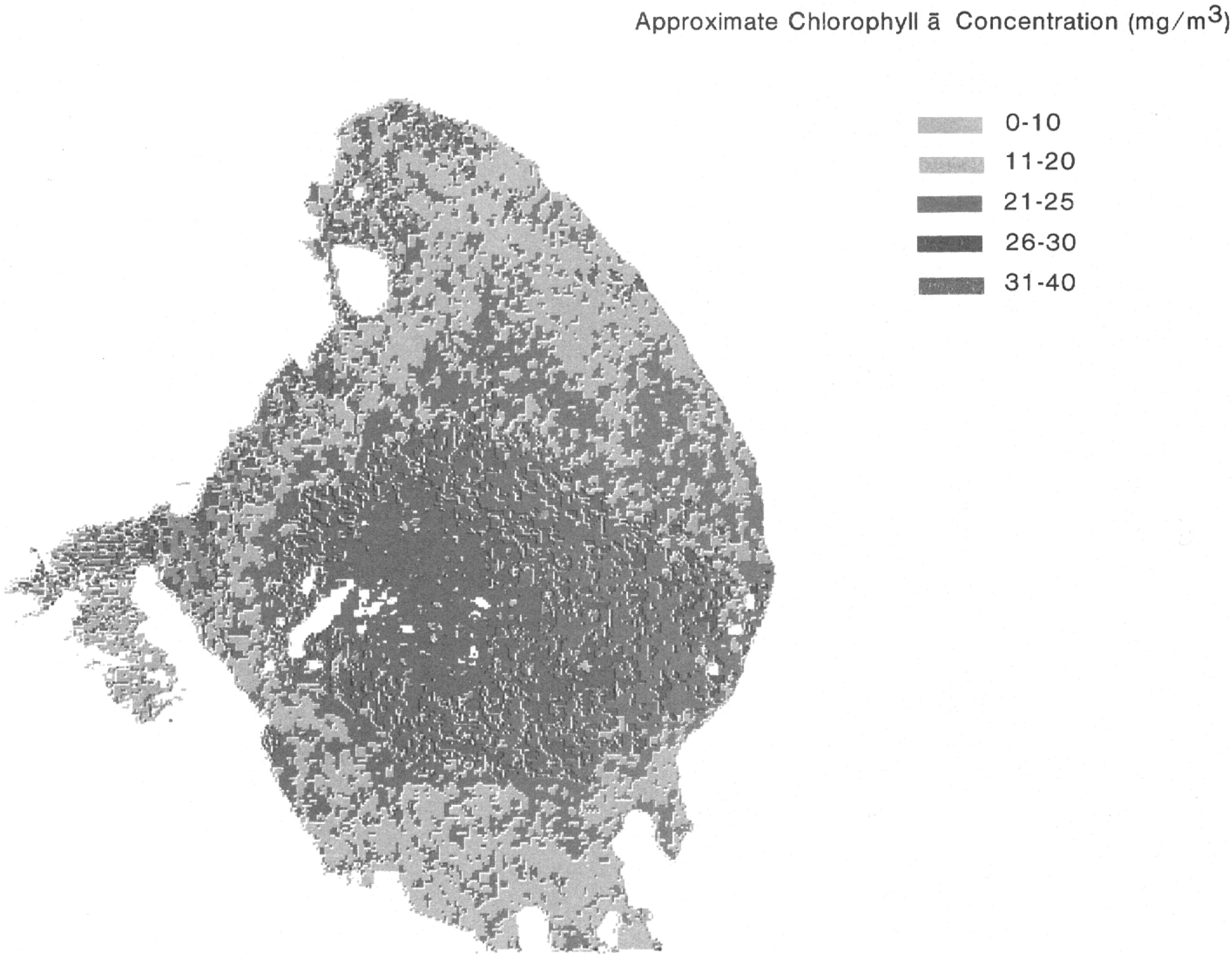


Figure 12. Chlorophyll ā distribution in Lake Okeechobee on February 4, 1975, based on LANDSAT radiance in Bands 6 and 7.

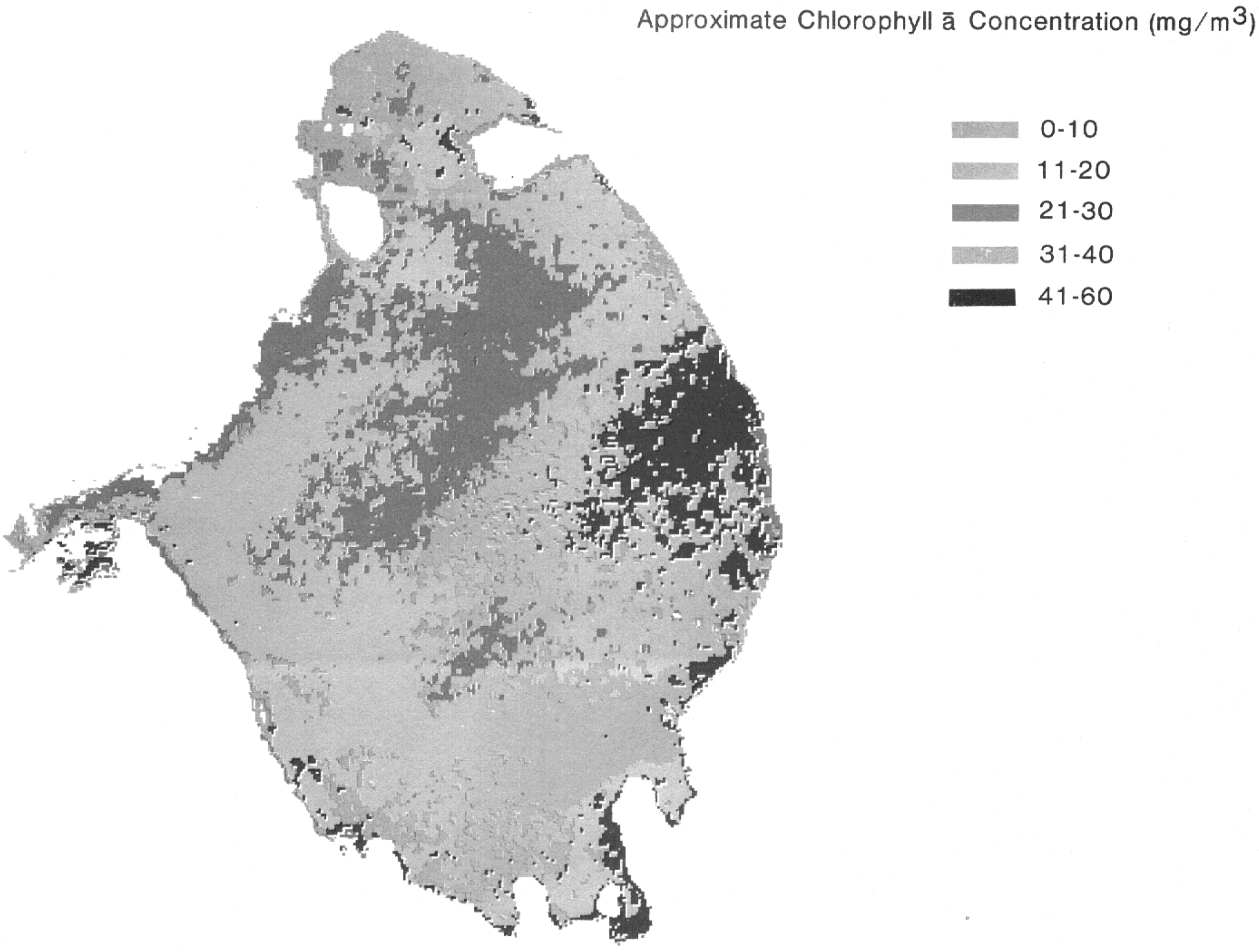


Figure 13. Chlorophyll ā distribution in Lake Okeechobee on May 5, 1975, based on LANDSAT radiance in Bands 4 and 7.

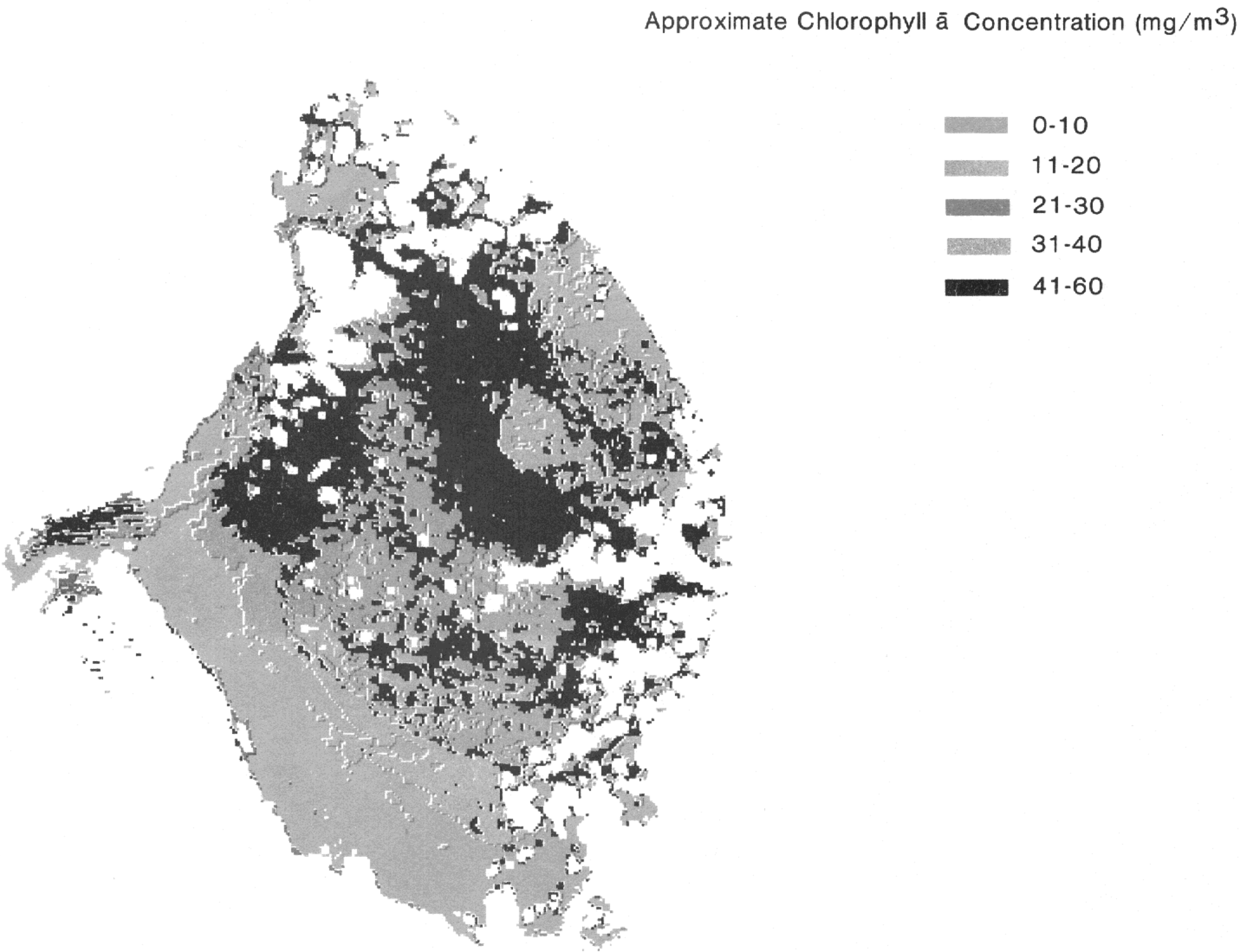


Figure 14. Chlorophyll ā distribution in Lake Okeechobee on September 8, 1975, based on LANDSAT radiance in Bands 5 and 6.